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HIGH SPIN LEVELS IN ^{70}Ga VIA $^{68}\text{Zn}(\alpha, \text{pn}\gamma)^{70}\text{Ga}$

C. MORAND (*), M. AGARD, J. F. BRUANDET, A. GIORNI,
J. P. LONGEQUEUE and TSAN UNG CHAN

Institut des Sciences Nucléaires, BP 257, 38044 Grenoble Cedex, France

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Résumé. — Nous avons étudié le noyau ^{70}Ga par la réaction $^{68}\text{Zn}(\alpha, \text{pn}\gamma)^{70}\text{Ga}$ à $E_\alpha = 23\text{--}40$ MeV au moyen de fonctions d'excitations, de mesures électroniques de durée de vie, de coïncidences promptes et retardées et de distributions angulaires des raies γ émises. Nous avons identifié des niveaux de spin $J^\pi \leq 9^+$ jusqu'à 2,9 MeV d'excitation, et précisé ainsi la composante sur la couche $(\nu 1g_{9/2})$ des niveaux yrast du ^{70}Ga .

Abstract. — The ^{70}Ga nucleus has been investigated via the $^{68}\text{Zn}(\alpha, \text{pn}\gamma)^{70}\text{Ga}$ reaction at $E_\alpha = 23\text{--}40$ MeV. The level scheme has been established by means of relative yield functions, electronic timing measurements, prompt and delayed coincidences and angular distributions of the emitted γ rays. The assignments of spins up to 9^+ to levels up to 2.9 MeV excitation energy specify the components of the $(\nu 1g_{9/2})$ subshell.

1. Introduction. — The first attempt to establish the level scheme of the odd-odd isotope ^{70}Ga was done by D. H. Rester *et al.* [1] who observed the internal conversion electrons and gamma rays produced by the $^{70}\text{Zn}(\text{p}, \text{n}\gamma)^{70}\text{Ga}$ reaction at $E_p = 1.5\text{--}5.0$ MeV. Then, besides studies by the thermal neutron capture reaction $^{69}\text{Ga}(\text{n}, \gamma)^{70}\text{Ga}$ [2, 3], ^{70}Ga was investigated by S. Tanaka *et al.* [4] by means of the (p, n) reaction at $E_p = 2.7\text{--}5.3$ MeV. The Stockholm group used $^{69}\text{Ga}(\text{d}, \text{p})$ at $E_d = 7.1$ MeV and $^{70}\text{Zn}(\text{p}, \text{n}\gamma)$ at $E_p = 3.5$ MeV (Z. P. Sawa [5]) and direct reactions $^{69}\text{Ga}(\text{d}, \text{p})$, $^{71}\text{Ga}(\text{d}, \text{t})$ and also γ -ray techniques with $^{69}\text{Ga}(\text{d}, \text{p}\gamma)$, $^{67}\text{Zn}(\alpha, \text{p}\gamma)$, $^{70}\text{Zn}(\text{p}, \text{n}\gamma)$ and $^{69}\text{Ga}(\text{n}, \gamma)$ reactions (S. E. Arnell *et al.* [6]), to give the first reliable level scheme of ^{70}Ga up to 1.6 MeV excitation energy. All previous works have been summarized by K. R. Alvar *et al.* [7]. The first spin assignments were done by M. R. Najam *et al.* [8] by means of a γ -ray study with the $^{70}\text{Zn}(\text{p}, \text{n}\gamma)^{70}\text{Ga}$ reaction at $E_p = 1.7\text{--}3.2$ MeV. The isomerism of the $J^\pi = 4^-$ state at 879 keV was uncovered by the same group, i.e. L. E. Carlson *et al.* [9] who also measured lifetimes by DSAM [10], and the time perturbed angular distribution (TPAD) of the 188 keV γ -ray was studied by D. A. Hutcheon *et al.* [11].

In ^{68}Ga we have already observed high spin levels up to $J^\pi = 11^+$ by means of the $^{65}\text{Cu}(\alpha, \text{n}\gamma)$ and

$^{66}\text{Zn}(\alpha, \text{pn}\gamma)$ reactions [12]. So it seems reasonable to hope to reach high spin states in ^{70}Ga via $^{68}\text{Zn}(\alpha, \text{pn}\gamma)^{70}\text{Ga}$ at $E_\alpha \simeq 30$ MeV. Indeed the $1g_{9/2}\text{--}2p_{3/2}$ proton splitting (1 972 keV in ^{69}Ga [13]) and the small $1g_{9/2}\text{--}2p_{1/2}$ neutron splitting (198 keV in ^{71}Ge [14]) enables us to build high spin states up to 9^+ . As a support we may note the work of C. C. Lu *et al.* [15] who used the $^{68}\text{Zn}(\alpha, \text{d})^{70}\text{Ga}$ reaction at $E_\alpha = 50$ MeV to strongly populate a state at 2.88 MeV which has the probable configuration $((\pi 1g_{9/2})(\nu 1g_{9/2}))_{9^+}$. The presence of the $(\nu 1g_{9/2})$ shell at lower energy in ^{70}Ga is also confirmed by the very useful spectroscopic work of D. A. Dohan *et al.* [16] using the direct reactions $^{69}\text{Ga}(\text{d}, \text{p})$ at $E_d = 10$ MeV and $^{71}\text{Ga}(\text{d}, \text{t})$ at $E_d = 16$ MeV.

2. Experimental procedure. — The $^{68}\text{Zn} + \alpha$ reaction at $E_\alpha \simeq 30$ MeV has two main outgoing channels : $^{68}\text{Zn}(\alpha, 2\text{n}\gamma)^{70}\text{Ge}$ which was used in our study of ^{70}Ge [17] and $^{68}\text{Zn}(\alpha, \text{pn}\gamma)^{70}\text{Ga}$ with a cross section (estimated by means of the γ transitions to the G.S.) which is 10 times smaller than that of the $(\alpha, 2\text{n})$ reaction. We shall only describe here the experimental set-up specific to the ^{70}Ga study and ask the reader to refer to the ^{70}Ge paper [17] for any further information.

We briefly mention the performance of :

— Yield functions at $E_\alpha = 23\text{--}25\text{--}31\text{--}33\text{--}40$ MeV (Fig. 1).

— $\gamma\text{--}\gamma$ coincidences at $E_\alpha = 31$ MeV in the $2\,048 \times 1\,024$ channels format (Fig. 3, 4).

(*) This work forms a part of a thesis.

— Electronic timing measurements at $E_\alpha = 30$ MeV in the 128×2048 format.

— γ angular distributions at $E_\alpha = 31$ MeV with $25^\circ < \theta < 150^\circ$ (Tables II, III).

3. Analysis of the data. — **3.1 YIELD FUNCTIONS.** — Usually the relative yield functions provide a powerful tool to ensure spin assignments, because in a stretched cascade of γ -rays, the intensity ratio $I(\gamma_1)/I(\gamma_2)$ (γ_1 denotes the upper transition) must increase with increasing the incident energy if the level emitting γ_1 has a larger spin than the level emitting γ_2 . This fact is not striking when considering the experimental data plotted in figure 1. Thus, as we cannot make use of yield functions which are not too significant, we shall only remember that in a $(\alpha; xp, yn, \gamma)$ reaction the yrast cascade generally appears to be dominant (see Fig. 5).

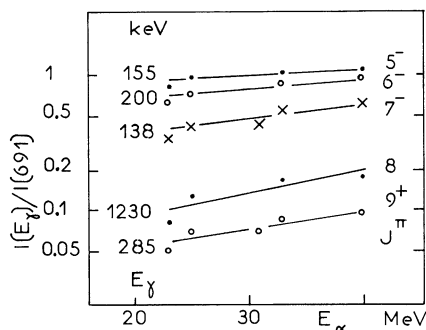


FIG. 1. — Relative yield functions of γ rays belonging to the yrast cascade.

To understand why the relative yield functions, measured in a large energy interval around the maximum of the absolute cross-section (i.e. from $E_\alpha = 23$ MeV to 40 MeV with the maximum located at $E_\alpha = 35$ MeV) are not significant, we must note again that the $(\alpha, pn)^{70}\text{Ga}$ channel is minor with respect to the $(\alpha, 2n\gamma)^{70}\text{Ge}$ one, so that the angular momentum distribution of the compound nucleus $^{72}\text{Ge}(\text{C.N.})$ is not preserved after the evaporation of 2n or pn, and a slight perturbation of this angular momentum distribution in the $(\alpha, 2n)$ main channel may provide a very large perturbation of the angular momentum distribution in the minor (α, pn) competing channel.

For illustration, in figure 2 are plotted for ^{70}Ge and ^{70}Ga at 31 MeV the relative side-feeding of all the levels with a given spin J . (We call side-feeding of a level the feeding which is not provided by an observable line.) Although spins are not known for every observed level of these nuclei, their contributions can be neglected because these levels are the most weakly fed. The curve of figure 2 is the angular momentum distribution of the C.N. calculated using the formula $\sigma_l = \pi \lambda^2 (2l + 1) T_l$, where the transmission coefficients T_l have been computed with the optical para-

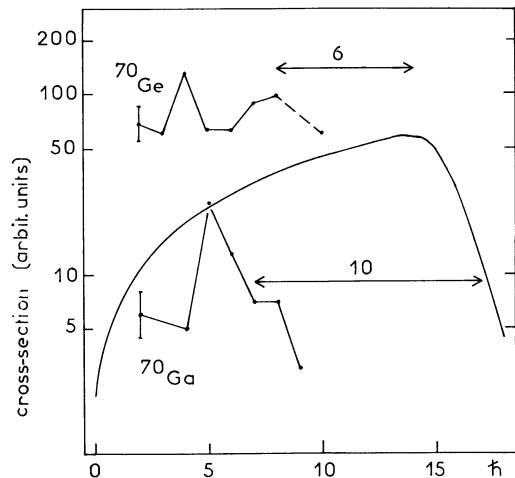


FIG. 2. — Relative side-feedings at $E_\alpha = 31$ MeV of ^{70}Ge and ^{70}Ga levels summed over all levels with a given spin J . The curve is the theoretical angular momentum distribution obtained with the formula $\sigma_l = 2\pi\lambda^2(2l + 1) T_l$.

meters extracted from the $^{68}\text{Zn}(\alpha, \alpha')$ elastic scattering at $E_\alpha = 31$ MeV by N. Alpert *et al.* [18]. The comparison between the curve and the experimental data shows that the evaporation of two neutrons and statistical γ -rays carries $\simeq 6\hbar$ out of the C.N., and that the evaporation of the pn couple and statistical γ -rays carries out $\simeq 10\hbar$. (These values are roughly obtained by estimating the distance between the part having negative slopes of the experimental and theoretical curves). If we assume, as it is usually done (and as we observed in ref. [12]) that an evaporated neutron carries out $1\hbar$, we find the difference $(10\hbar - 6\hbar) - 1\hbar = 5\hbar$ for the evaporated proton, which will be too much for one proton ejected with the 6 MeV Coulomb barrier energy.

In figure 2, it may be easily noted that the experimental spin distribution in the ^{70}Ge residual nucleus differs from the theoretical angular momentum distribution of the C.N., even after a translation of $6\hbar$ representing the evaporation of 2n and statistical γ -rays. This perturbation might be different at $E_\alpha = 23$ MeV and $E_\alpha = 40$ MeV where other outgoing channels become predominant and this might explain why the relative yield functions for a minor channel $(\alpha, pn\gamma)^{70}\text{Ga}$ are not significant. We did not encounter such a problem when studying [12] the reactions $^{65}\text{Cu}(\alpha, n\gamma)^{68}\text{Ga}$ at $E_\alpha = 12$ -21 MeV and $^{66}\text{Zn}(\alpha, pn)^{68}\text{Ga}$ at $E_\alpha = 25$ -40 MeV because probably these channels are predominant in these energy interval.

3.2 γ - γ COINCIDENCES. — We used the prompt and delayed coincidences technique described in refs. [17, 19]. It consists of recording events either within a time interval $t < 15$ ns (prompt coincidences), or within a time interval $25 < t < 50$ ns (delayed coincidences). Although the coincidences occur between the signals of the two detectors, the fact that the

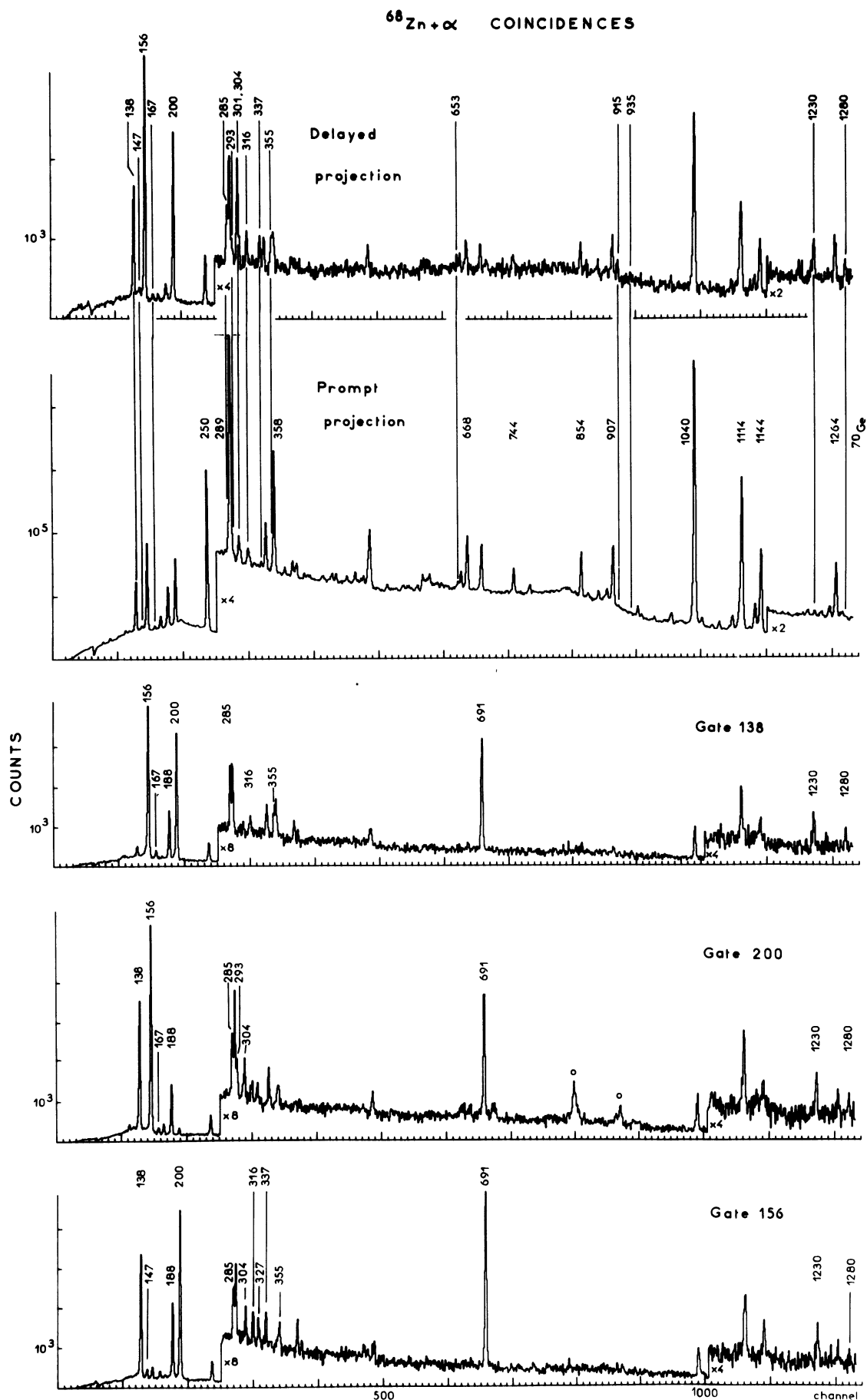


FIG. 3. — Upper part : projection spectra on the channel which started the TAC of the prompt and the delayed coincidence matrices obtained by the $^{68}\text{Zn} + \alpha$ reaction at $E_\alpha = 31$ MeV. The γ ray feeding of the isomeric state at 879.1 keV is enhanced in the delayed projection. Lower part : three spectra in prompt coincidence with events in the indicated gate regions and with subtracted background. Peaks marked with a (0) in the 200 keV gate spectrum are due to the back-scattering of the strong 1 040 and 1 114 keV γ -rays of ^{70}Ge .

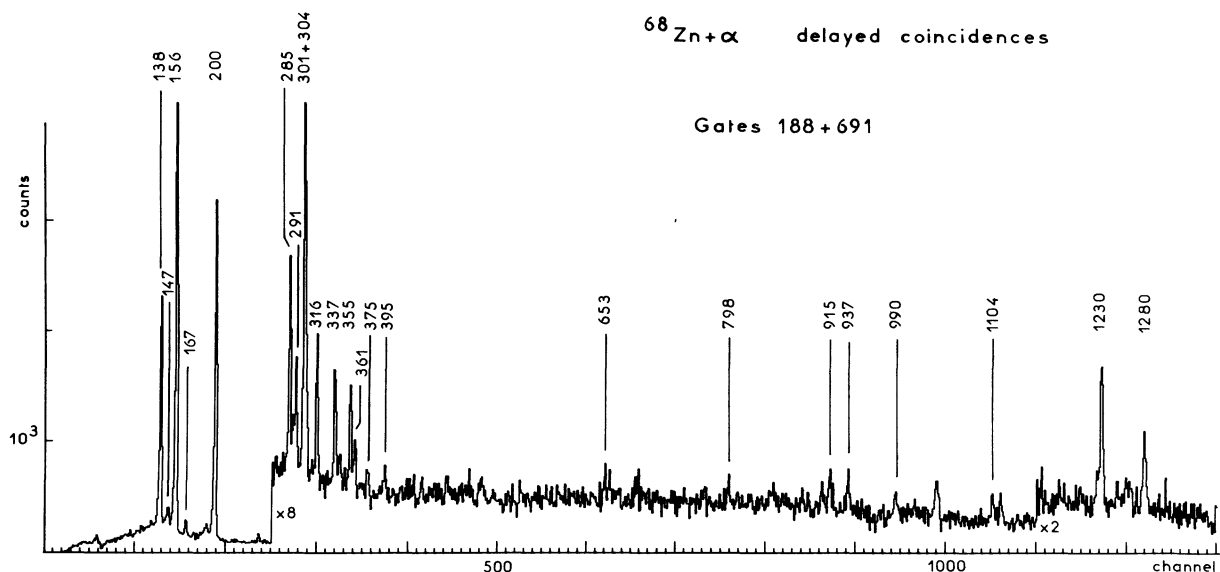


FIG. 4. — Sum of the 188 and 691 keV gated spectra taken in delayed coincidences with the energy conditioned on the channel which stopped the TAC. All the γ -rays feeding the isomeric state at 879.1 keV emerge in a striking manner.

cyclotron beam is pulsed (70 ns period at $E_\alpha = 31$ MeV) is very important for the delayed coincidences. As a matter of fact, the random coincidence rate being $N_r = \tau N_1 N_2$ ($\tau = 10$ ns, N_1 and N_2 are the counting rates of detectors 1 and 2, detector 1 starts the TAC, and detector 2 stops the TAC), and the counting rate N_2 located in the time interval between the beam bursts being lower by a factor of 100 than it would be during the pulse, so the random rate N_r of the delayed coincidences is much less than with a non pulsed beam. Comparison between prompt and delayed coincidences projections (see Fig. 3) exhibits γ -rays feeding directly or indirectly the isomeric state at 879 keV, which are enhanced in the delayed spectrum. In figure 3 the prompt projection has been made on the channel which started the time-to-amplitude-converter (TAC) with no energy condition on the pulse which stopped the TAC. The delayed projection on the other hand was performed with the condition $0 < E_\gamma < 190$ keV or $370 < E_\gamma < 700$ keV, an energy range where the greatest density of ^{70}Ga delayed γ -rays (Compton and photoelectric) is found. The γ -rays feeding the isomeric level may be seen also (Fig. 4) in the spectrum sum of the 188 keV and 691 keV gates taken in the delayed coincidences, on the channel which stopped the TAC. This method of delayed coincidences is very sensitive : thus are also spotted some γ -rays which could not be placed in the level scheme, the study of their angular distributions and yield functions also being impossible since they are masked in the prompt coincidences and in the single spectra.

Because of the predominant $(\alpha, 2n)^{70}\text{Ge}$ outgoing channel, the exploitation of the prompt coincidences has been rather difficult : coincidence between two γ -rays was ensured only by careful comparison

between the gated spectrum and the background spectrum. The gated spectrum was taken with few (two or three) central channels of the gated peak, and the background was taken with more than twenty channels around the peak where no photoelectric peaks are apparent, that in order to increase the signal/background ratio. In figure 3 are shown some gated spectra with 1 024 channels but we have also used inverse gated spectra with 2 048 channels and better resolution (Fig. 4) to establish the coincidence matrix of table I.

3.3 ELECTRONIC TIMING MEASUREMENTS. — We have measured again nano-second order lifetimes for the $^{68}\text{Zn} + \alpha$ reaction with a time pick off different from the one previously used [17]. The zero time signal was not derived from the radio-frequency of the cyclotron, which inconveniently has a variable phase shift with respect to the beam pulses impinging on the target, depending on the adjustment of the magnetic field inside the cyclotron. The zero time signal was provided by a photomultiplier tube with a plastic scintillator which detected the electrons ejected out of the target and accelerated by a 20 kV potential difference. The time resolution of this experimental set up was found to vary from 6 ns (FWHM) at 138 keV (3.3 ns edge slope) to 4 ns (FWHM) at 1 114 keV (0.6 ns edge slope).

We obtained the half lives $T_{1/2} = (22 \pm 2)$ ns for the known isomeric state at 879.1 keV (in perfect agreement with other measurements [9, 11]), and $T_{1/2} = (24 \pm 4)$ ns for the new isomeric state at 1 086.7 keV, the worse precision being due to the weakness of the 185 keV transition. We must also point out that the 1 109 keV transition in ^{70}Ge which previously looked like delayed [17] is found to have

TABLE I
Coincidence matrix of the main cascade

Gate \ E_γ	138	147	155	167	188	200	285	291	301	304	316	337	355	395	653	916	937	990	1 230	1 280
138	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
155	x	x	—	x	x	x	x	x	—	x	x	x	x	x	x	x	x	x	x	x
188	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
200	x	—	x	x	x	—	x	x	—	x	x	—	—	x	?	?	—	—	x	x
285	x	—	x	—	x	x	—	—	—	—	—	—	—	—	—	—	—	—	x	x
1 230	x	—	x	—	x	x	x	—	—	—	—	—	—	—	—	—	—	—	x	x

The question mark indicates that the coincidence peak may be provided by back-scattering.

$T_{1/2} < 0.6$ ns in the present experiment. All other transitions in ^{70}Ga have $T_{1/2} < 4$ ns, so all quadrupolar γ -ray we have measured (like the 337 and 355 keV) have E2 multipolarity (any M2 with $E_\gamma < 1\,300$ keV would have an observable lifetime [20]).

3.4 γ -RAY ANGULAR DISTRIBUTIONS. — They have been measured at 8 angles ($25 < \theta < 130^\circ$) using a 90 cm^3 detector with a 3 keV resolution at 1.33 MeV, and at 4 angles ($25 < \theta < 90^\circ$) using a 10 cm^3 detector with a 1 keV resolution at 122 keV. Their analysis was

performed with the code DIAM [21] written with the formulas of T. Yamazaki [22]. As explained in [17], we choose the solution with the best χ^2 , and moreover, when this last criterion is ambiguous, we prescribe that for a given level, the alignment parameter coefficient α_2^f deduced from the angular distribution analysis of the γ -rays feeding this level, should be as near as possible to the α_2^i deduced from the data of the γ -ray emitted by the level. This criterion induces the alignment to decrease as the nucleus is deexcited down the yrast cascade, with a starting value near 1 (i.e. maximum).

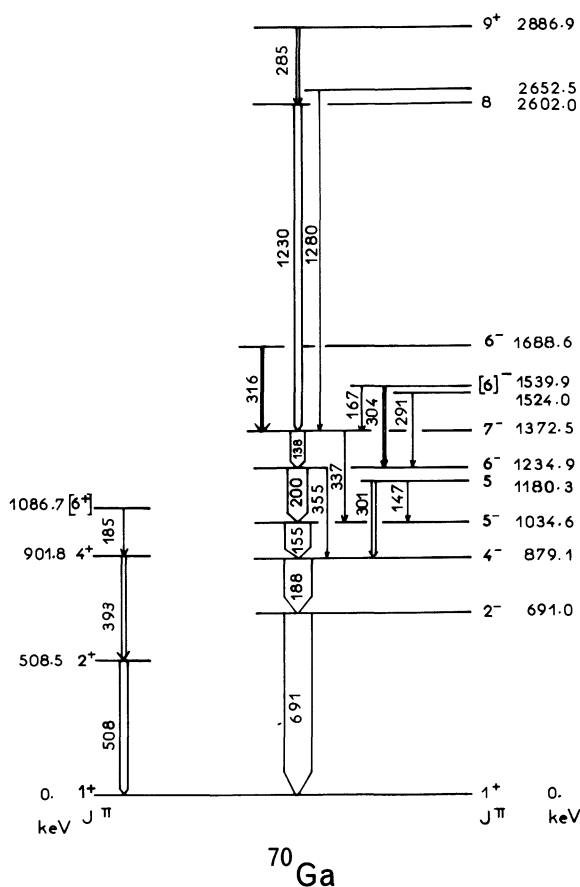


FIG. 5. — Decay scheme of the ^{70}Ga nucleus as a result of the present measurements.

4. Discussion. — 4.1 SPIN AND PARITY ASSIGNMENTS. — They are summarized in the decay scheme (Fig. 5). Table II presents the angular distribution analysis, and in table IV are listed the component configurations extracted from refs. [15, 16].

We shall not discuss the lowest states at 508.5 keV and 691.0 keV. In fact the 508 keV γ -ray is perturbed by the 511 keV, but data from refs. [8, 16] ensure the characteristics $J^\pi = 2^+$. We did not extract the 691 keV γ -ray angular distribution because of the presence of the neutron peak in Ge detector but refs. [8, 9] give $J^\pi = 2^-$ with a component of the $((\pi 1f_{5/2})(\nu 1g_{9/2}))_2^-$ configuration for the 691 keV level [16].

— The 879.1 keV state. — The E2 character (angular distribution and $T_{1/2} = 22$ ns lifetime) of the 188 keV γ -ray originating from this level assigns $J^\pi = 4^-$ to the level as suggested by refs. [8, 9]. The (d, p) experiment of ref. [16] gives to it the main configuration component $((\pi 2p_{3/2})(\nu 1g_{9/2}))_4^-$ with a spectroscopic factor $S = 0.7$. However this configuration seems to be strongly mixed with others when having regard to the recent g factor value measured by T. Taylor and D. A. Hutcheon [23].

— The 901.8 keV state. — The angular distribution of the 393 keV γ -ray does not give any choice between the characteristics $J^\pi = 3^+$ or 4^+ (the positive parity is deduced from the lifetime consideration : $T_{1/2} < 1.4$ ns), but we discard the $J^\pi = 3^+$ solution

TABLE II
Angular distribution analysis

E_γ (°)	$E_i \rightarrow E_f$ (°)	$A_2 \pm \Delta A_2$ (°)	$A_4 \pm \Delta A_4$ (°)	I_0 (°)	$J_i \rightarrow J_f$ (°)	σ (°)	$\alpha_2^i \rightarrow \alpha_2^f$ (°)	χ^2	$\delta \pm \Delta\delta$ (°)	Multipolarity (°)
137.6	1 372.5 1 234.9	-0.29 ± 0.03	-0.01 ± 0.03	260	$7^- \rightarrow 6^-$	1.1	0.93 0.90	0.9	0 ± 0.1	M1
146.8	1 180.3 1 034.6	0.23 ± 0.05	-0.2 ± 0.1	53	$5 \rightarrow 5^-$	1.5	0.77 0.62	0.9	1.1 ± 0.3	
155.5	1 034.6 879.1	-0.27 ± 0.04	-0.06 ± 0.05	750	$5^- \rightarrow 4^-$	1.4	0.79 0.74	1	0 ± 0.1	M1
167.4	1 539.9 1 372.5	-0.37 ± 0.07	0.25 ± 0.08	23	$8 \rightarrow 7^-$ $7 \rightarrow 7^-$ $6 \rightarrow 7^-$	0.5 3 1	0.99 0.96 0.56 0.47 0.93 0.90	2 4.3 2	0 ± 0.1 - 3 0.1 ± 0.1	←
184.9	1 086.7 901.8	0.38 ± 0.21	0.2 ± 0.1	60	$6^+ \rightarrow 4^+$ $5^+ \rightarrow 4^+$ $4 \rightarrow 4^+$	1 1.2 1	0.62 0.52 0.86 0.75 0.85 0.72	1 1 1.3	0.4 ± 0.3 0.6 0.1 ± 0.1	
188.1	879.1 691.0	0.26 ± 0.04	-0.03 ± 0.06	900	$4^- \rightarrow 2^-$	2	0.48 0.35	0.9	0 ± 0.1	E2
200.3	1 234.9 1 034.6	-0.23 ± 0.01	-0.07 ± 0.01	430	$6^- \rightarrow 5^-$	1.5	0.83 0.79	1	0 ± 0.1	M1
284.8	2 886.8 2 602.0	-0.22 ± 0.1	-0.2 ± 0.1	60	$9^+ \rightarrow 8$	1.5	0.97 0.95	1.5	0 ± 0.2	←
301.2	1 180.3 879.1	-0.22 ± 0.03	-0.1 ± 0.1	150	$5 \rightarrow 4^-$	1.9	0.65 0.60	1.5	0 ± 0.1	
304.3	1 539.9 1 234.9	0.38 ± 0.2	-0.1 ± 0.1	57	$8^- \rightarrow 6^-$ $6 \rightarrow 6^-$	1 1	0.96 0.90 0.93 0.84	1.2 1	0.1 ± 0.1 0.4 ± 0.1	←
316.1	1 688.6 1 372.5	-0.25 ± 0.05	0.03 ± 0.06	90	$6^- \rightarrow 7^-$ $7 \rightarrow 7^-$ $8 \rightarrow 7^-$	1.5 3.2 1.2	0.84 0.81 0.50 0.41 0.94 0.92	0.2 0.4 0.8	0.05 ± 0.1 - 3.2 0 ± 0.1	←
337.1	1 372.5 1 034.6	0.22 ± 0.1	0.04 ± 0.1	38	$7^- \rightarrow 5^-$	3	0.56 0.52	1.1	0 ± 0.1	E2
393.3	901.8 508.5	0.25 ± 0.05	0.03 ± 0.07	130	$4^+ \rightarrow 2^+$ $3^+ \rightarrow 2^+$	2.4 1.8	0.36 0.26 0.45 0.31	1 1	0.16 ± 0.2 0.5 ± 0.3	E2
1 229.9	2 602.0 1 372.5	-0.23 ± 0.13	0.02 ± 0.2	200	$8 \rightarrow 7^-$ $9 \rightarrow 7^-$	2.1 4	0.81 0.79 0.53 0.46	0.8 1	0 ± 0.2 - 1.3	←

(°) Energy in keV (0.1 keV precision) of the studied γ -ray.

(°) Energies of the initial and final levels.

(°) Angular distribution Legendre polynomial coefficients from $I(\theta) = I_0(1 + A_2 P_2(\cos \theta) + A_4 P_4(\cos \theta))$ with $I_0(691) = 1\,000$.

(°) Spin parity J_i^π of the initial level E_i and J_f^π of the final level E_f .

(°) Width of the gaussian distribution of the magnetic substates in unit of the initial level spin ($0.5 < \sigma < 3$) as defined by ref. [22].

(°) Alignment parameter coefficients α_2^i and α_2^f of the initial and final level as defined by Yamazaki [22].

(°) Mixing ratios [22].

(°) The arrow indicate the solution preferred by the angular distribution analysis.

because of the absence of a 901 keV E2 transition to the GS $J^\pi = 1^+$. Thus we assign $J^\pi = 4^+$ to the level as suggested by ref. [8]. This state has therefore the $((\pi 2p_{3/2})(\nu 1f_{5/2}))_{4^+}$ component with a spectroscopic factor $S = 0.2$ [16].

— *The 1 034.6 keV state.* — M. R. Najam *et al.* [8] gave to it a $J > 4$ limitation. It decays to the $J^\pi = 4^-$ level at 879.1 keV by a $L = 1\,155$ keV γ -ray, which belongs to the yrast cascade and has a relative yield function increasing with the incident energy so we assign $J = 5$ to the level. The negative parity is extracted from ref. [16] implying a $((\pi 2p_{3/2})(\nu 1g_{9/2}))_5$ configuration and $S = 1.5$.

— *The 1 086.7 keV state.* — The 185 keV weak transition has an angular distribution with $A_2 > 0$ and a half-life $T_{1/2} = 24$ ns, which gives 4 W.U. for the E2 multipolarity (a typical value for a non collective E2 transition in this mass region). So this new level may have $J^\pi = 6^+$, but the difficulty in extracting information about the 185 keV γ -ray mixed with the strong 188 keV line makes these suggestions questionable.

— *The 1 180.3 keV state.* — The angular distribution analysis of the two transitions 301 keV and 147 keV suggests $J = 5$ for this new non yrast level and the positive parity having regard to the strong

TABLE III

Branching ratios for some levels

Initial level (keV)	Outgoing γ -rays and their branching ratios	
1 180.3	147	301
	0.3	0.7
1 234.9	200	355
	0.94	0.06
1 372.5	138	337
	0.91	0.09
1 539.9	167	304
	0.3	0.7

The listed branching ratios are estimated with 20 % relative error.

TABLE IV

Configuration of some ^{70}Ga levels

E_x (°)	J^π	l_n	S (°)	Configuration	
—	—	—	—	π	ν
691.0	2^-	not seen	—	$1f_{5/2}$	$1g_{9/2}$
879.1	4^-	4	0.7	$2p_{3/2}$	$1g_{9/2}$
		2	0.04	$2p_{3/2}$	$2d_{5/2}$
901.8	4^+	3	0.2	$2p_{3/2}$	$1f_{5/2}$
1 034.9	5^-	4	1.5	$2p_{3/2}$	$1g_{9/2}$
1 234.9	6^-	4	0.76	$2p_{3/2}$	$1g_{9/2}$
1 372.5	7^-	not seen	—	$1f_{5/2}$	$1g_{9/2}$
1 688.6	6^-	4	0.45	$2p_{3/2}$	$1g_{9/2}$
2 886.7	9^+	not seen	—	$1g_{9/2}$	$1g_{9/2}$

(°) Excitation energy in keV (precision ± 0.5 keV).

(°) l_n and S extracted from the (d, p) measurement of ref. [16].

mixing ratios $\delta = 1.1$ of the not delayed 147 keV γ -ray which has the M1/E2 multipolarity. But it is too weakly fed to ensure a firm spin assignment.

— *The 1 234.9 keV state.* — This state has been reached through the (d, p) reaction with $l_n = 4$ [16] and through the (α , d) reaction at $E_\alpha = 50$ MeV [15]. The $L = 1$ character ($A_2 < 0$) and the relative yield function of the 200 keV γ -ray which belongs to the yrast cascade, assign $J = 6$ to this level, which has a $((\pi 2p_{3/2})(\nu 1g_{9/2}))_{6-}$ configuration with $S = 0.76$. The multipolarity of the 355 keV E2 transition is rather difficult to extract because this γ -ray is mixed with the strong 358 keV transition in ^{70}Ge .

— *The 1 372.5 keV state.* — The $L = 1$ character ($A_2 < 0$), the relative yield function of the 138 keV γ -ray, which belongs to the yrast cascade and the E2 337 keV γ -ray, which de-excite this level, assign $J^\pi = 7^-$. A 138 keV transition had already been seen

in ref. [8] but it was incorrectly attributed to the tantalum absorber. This new level, not seen in the (d, p) reaction, probably has the $((\pi 1f_{5/2})(\nu 1g_{9/2}))_{7-}$ configuration which is the cheapest way to build a 7^- level : the fact that it decays to the $((\pi 2p_{3/2})(\nu 1g_{9/2}))_{5-, 6-}$ states by a pure M1 transition and a E2 transition with the branching ratios 0.9 and 0.1, indicates that it must be describe in the simple framework of the shell model and therefore it may be obtained simply by the jump of a nucleon to an orbit without change of parity. Now the center of gravity of the $((\pi 2p_{3/2})(\nu 1g_{9/2}))$ shell calculated for the levels reached with $l_n = 4$ in the (d, p) experiment by Dohan *et al.* [16] is located at 1 004 keV. If we add to this value the 584 keV $2p_{3/2}$ - $1f_{5/2}$ proton splitting found in ^{69}Ga [13], we obtain for the $((\pi 1f_{5/2})(\nu 1g_{9/2}))$ a value of 1 538 keV not too far from the 1 372 keV state.

— *The 1 539.9 keV state.* — The 167 keV and 304 keV transitions which de-excite this level are too weak to ensure the angular distributions suggestion $J = 6$, which is preferred to $J = 8$ solution only because the $J = 8$ yrast level is the 2 602 keV state.

— *The 1 688.6 keV state.* — Although the $L = 1$ behaviour of the 316 keV γ -ray is doubtful with regard to its weak intensity and does not permit any choice between $J = 6$ and $J = 8$, we assign $J = 6^-$ to this level : indeed it has been populated in the (d, p) experiment [16] with $l_n = 4$ and it would have a $((\pi 2p_{3/2})(\nu 1g_{9/2}))_{6-}$ component with $S = 0.45$. However we must point out that the (α , d) reaction [15] only populates the 6^- state at 1 235 keV although this 1 688.6 keV state contains the same configuration.

— *The 2 602.0 keV state.* — The angular distribution and yield function of the 1 230 keV γ -ray give $J = 8$ for this level, but we have not too much confidence in the extraction of intensity in the single spectra, because the presence of the Compton edge of the 1 523 keV γ -ray of ^{70}Ge makes the background determination difficult.

— *The 2 886.9 keV state.* — We suggest $J = 9$ to this level according to the result of the angular distribution and yield function of the 285 keV γ -ray (in spite of a mixing with the strong 289 keV γ -ray in ^{70}Ge). So there is no doubt that it is the $((\pi 1g_{9/2})(\nu 1g_{9/2}))_{9+}$ state seen at 2.88 MeV by C. C. Lu *et al.* [15]. The assignment confirms the $J = 8$ suggestion for the 2 602.0 keV state which may be described by the $((\pi 1g_{9/2})(\nu 1g_{9/2}))_8$ configuration. The position at lower excitation than the $J = 9^+$ state is in agreement with the Nordheim's weak rule.

The 1 224 keV and 2 652.5 keV states are too weakly fed to allow spin assignment.

5. Conclusion. — As it was expected according to the very useful works of D. A. Dohan *et al.* [16] and C. C. Lu *et al.* [15], we found high spin levels in ^{70}Ga up to 9^+ based on the $(\nu 1g_{9/2})$ orbital. However, with

regard to the poor cross section of the $^{68}\text{Zn}(\alpha, \text{pn}\gamma)$ reaction with respect to the $^{68}\text{Zn}(\alpha, 2\text{n})$ competing channel, we can warrant the spin assignments in the yrast cascade (with some doubt about the 2 602.0 keV state) but not for the other states. It is interesting to point out that all members except one (the 3^- state which is perhaps non yrast) of the $(\pi p_{3/2}, \nu g_{9/2})$ configuration have been found. We note also that the

highest levels of ^{70}Ga do not look like a ^{69}Ga core coupled with a $\nu 1g_{9/2}$ neutron as noted for the ^{68}Ga nucleus [12] where such states have been described by a ^{67}Ga core plus a $\nu g_{9/2}$ neutron.

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